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REPORT No. 927

The Drag Of A 1/6 Scale Model Of The 3000-lb. Bomb M118 From A Mach Number Of 0.7 To 1.2 As Obtained From Free Flight Firings

L. C. MacALLISTER

DEPARTMENT OF THE ARMY PROJECT No. 503-03-002
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0136

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

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LCMacAllister/psg
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ABSTRACT

The drag coefficients of a 1/6 scale model of the 3000-pound Bomb M118 as obtained from free flight firings and full scale values as inferred from range drops are given for a Mach number range of 0.7 to 1.2. Comparison of the model and the full scale drag data indicate that the two are in good agreement only if the prevailing yaw levels of the full scale bomb are taken into account.

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INTRODUCTION

The pertinent aerodynamic information on bombs which is necessary to prepare bombing tables is usually obtained from full scale drops. This procedure is both costly and lengthy. Hence it was thought important to explore the possibility of obtaining the necessary information by model firings. It should be noted that the variables that enter into the determination of the trajectory of a dropped bomb are probably too numerous and too interrelated with launching conditions to permit a highly accurate solution from knowledge of the bomb's basic drag properties along. A model program should be able to provide the basic drag information that could permit simplification of the necessary full scale program.

A primary question to explore is the importance of Reynolds number effects in the scaling of the bomb shape to a model size suitable for firing in the range. Therefore a model program to provide information on the aerodynamic properties of the 3,000-pound M118 bomb shape at transonic velocities was carried out in the Transonic Range facility(1).

The test considered of launchings of approximately one-sixth scale models through the range instrumentation to determine data that would yield the drag, stability, and damping properties of the models.

Since drag determinations are usually completed well in advance of the more complex yawing motion parameters only the drag results and their preliminary evaluation is given here.

TEST PROGRAM

The test program consisted of two firings of twelve models each. Models of two types (Table I), differing in the position of the center of mass (Figs. 1, 2) were launched in wood-plastic sabots (Figs. 2, 3)(2) from a tank mounted 155mm smoothbore gun tube (Fig. 4). The sabots were so constructed as to hold the models at one and a half degrees angle to the boreline of the launching tube. This arrangement insured that sufficient yaw would be developed to permit analysis of the yawing motion.

The model bomb disengaged from the sabot within the distance separating the gun from the blast shield protecting the range building. The fragmented parts of the sabot were collected and deflected by the shield; the model then passed through a series of eighteen-inch ports into the instrumented portion of the range.

At each of the range's twenty-five spark stations horizontal and vertical projections of the model were obtained. At twelve stations the respective times of flight were recorded by 1.6 megacycle counters. Twenty-two undamaged models successfully traversed the full range. Two

of the models were damaged by sabot failure[1] in launching, although one of these flew through the range satisfactorily.

All models were provided with an inch-wide salt band on the nose to assure early development of a turbulent boundary layer. This was done since the full scale bomb usually operates at Reynolds numbers where a turbulent layer can be expected.

REDUCTION OF DATA

The two photographic plates of each timing station were measured on optical comparators. Spatial position of the center of mass was determined from these measurements geometrically. These data, together with the time of flight data, were fitted to the following form on high speed el ctronic computers.[3, 4]

$$t - t_0 = a\bar{z} + b\bar{z}^2 + c\bar{z}^3$$

Where $\bar{z} = z - z^*$

and z^* is an arbitrary point approximately in the center of timing data. The drag coefficient evaluated at the Mach number associated with z^* is given by:

$$C_D = -\frac{8}{\pi} \cdot \frac{m}{\rho d^2} \cdot \frac{2b}{a} = \frac{\text{Drag Force}}{\frac{\rho V^2}{2} \cdot \frac{\pi d^2}{4}} = \frac{8}{\pi} K_D$$

The values for the drag coefficients obtained are given in Table II together with the statistical error, the Mach number, and the prevailing yaw levels. The yaw drag coefficient is defined by:

$$K_D = K_{D_o} + K_{D_{\delta^2}} \cdot \delta^2$$

[1] Both failures occurred in the plastic base elements of the sabot. This probably was due to variability of properties in the initial plastic castings (used for the first time) since failures occurred at medium, rather than maximum, test loadings.

In order to establish the zero yaw drag curve, values of the drag coefficient obtained for lower yaw levels[1] were fitted as a function of Mach Number alone. This curve was used to adjust blocks of the data to a common Mach number so that the variation with yaw could be determined. This variation was, in turn, used to correct the data to zero yaw conditions so that a final variation with Mach number could be determined.

RESULTS

Model Drag

The model drag coefficients are given as a function of their Mach numbers in Table II and Figure 5 for zero yaw. A curve representing a constant yaw level of four degrees (sixteen squared degrees) is also given (accelerometer drop data indicated full scale yaws of 3 degrees or less). The effect of this level of yaw was to increase the drag coefficient about 14% at the lower subsonic test speeds. This percentage variation generally holds through the early part of the drag rise until approximately $M = 0.97$. In this latter region the yaw effects appear to decrease and between Mach numbers 1.0 and 1.075 the yaw drag coefficient was not clearly determined but appeared to be small[2]. Above $M = 1.10$ the percentage change of drag due to yaw effect was about half that at subsonic speeds and decreased with increasing Mach number. A plot of the yaw drag coefficient as a function of Mach number is given in Figures 3, 6 and 7.

Flow Pattern

The nature of the variation of the drag coefficient relates quite closely to observable features of the flow patterns about the projectiles.

The drag coefficient rises slowly from the lowest test Mach number of 0.7 up to approximately $M = 0.85$ with no observable disturbance in the flow field (Figs. 8, 9). This trend is probably due to flow compressibility effects and alters near a Mach number of .855 when local shocks appear on the corner of the ogive and at the boattail (Fig. 10). The onset of local shock patterns appear to disturb the viscous layer. The boundary layer and the wake seem more pronounced in the shadowgraphs, although the former does not separate under any of the observed yaw conditions. The dissipative effects of the shock formations and the disturbance of the viscous layer produce a higher rate of change of the drag coefficient with Mach number. The drag coefficient curve increases almost linearly with Mach number as the local shock formations grow

---

1 Mean squared yaws less than $3^{\circ 2}$.

2 This behavior is determined from models with an average yaw level of 2 degrees. Since relatively large variations in the flow characteristics occur for minor changes in yaw or Mach number near sonic speeds it is questionable whether this trend can be extrapolated to yaw conditions other than those achieved in the test.

(Fig. 11) until a Mach number of 0.97 is reached. At this latter point the curve steepens sharply, coinciding with a general development of supersonic flow behind the ogive. A waist shock occurs about the body, the flow reaccelerates on the afterbody and a shock system is established ahead of the fins. Local shocks also begin to appear, associated with the fins and the wake (Fig. 12). It appears that the local flow about the model is mainly supersonic and the shock system seems general rather than localized.

A bow wave appears in the shadowgraphs at a Mach number of 1.00 (Figs. 13, 14) and the slope of the drag curve decreases with increasing Mach number to the end of the test data at M = 1.25 (Figs. 15, 16).

Two further points, or rather suppositions might be noted: The fin shock pattern appears to stabilize at M = 1.09 and the data might support a minor break in the slope of the curve at this point; secondly the aft and bow shock formations appear to stabilize at the highest test Mach numbers indicating that the drag curve may be near a maximum.

This discussion is summarized in Fig. 16 a.

ESTIMATES OF FULL SCALE PERFORMANCE AND COMPARISONS[1]

In order to obtain estimates for the drag of the full scale bomb the difference in the surface skin frictional effects between the model and the full scale were computed using subsonic flat plate formulae[(5)]. Two conditions were considered: 1) the full scale bomb at zero yaw, equivalent Mach numbers and at essentially sea level atmospheric conditions; 2) the full scale bomb at zero yaw, and at the atmospheric conditions as recorded on a particular drop[(6)]. Curves representing these estimates are given in Figure 17 together with the model drag curve for 4 degrees average yaw to indicate the relative magnitude of yaw and scale effects. The curve corresponding to the atmospheric conditions prevailing for the drop is approximately 15% below the model curve in the lower subsonic portion and about 3% below it at M = 1.2.

Three determinations of the drag properties of the bomb are given in Figure 18. One is the drag curve obtained from accelerometer measur - ments on a full scale drop test. The yaw records for this drop indicat d yaw levels of about two degrees just after launching and when the bomb neared sonic speed. The second is the drag curve being used for preparations of bombing tables by the Computing Laboratory. This latter curve was deduced, initially, from all forms of drag data on models and on full scale configurations and was then adjusted to a best match of

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1 Discussions with Mr. E. S. Martin, Bombing Tables Branch, Computing Laboratory, Dr. A. S. Galbraith and Mr. L. Maynard, Theory Branch, EBL, have be n very helpful in this s ction.

of impact and time of flight data for a wide variation of drop conditions. The full scale estimates obtained from the firing range model data are also replotted in Figure 18 for average yaw levels of zero and four degrees.

It appears that the model curve is comparable with the curve used for bombing tables up to a Mach of one if average yaw levels of one to two degrees are probable. Above M = 1 the bombing table curve disagrees with the model curve unless average yaws of about four degrees are assumed. The accelerometer data curve is best determined at the higher Mach numbers and in this region it essentially agrees with the model curve. Estimated errors[6] for the lower portion of the accelerometer curve are such that it may be compatible with either of the other curv s.

In comparing overall results the source of the data should be considered. The free flight range test provides a highly accurate drag determination for the model fired; drag is usually determined for zero (or small) yaw. These results must be corrected for scale effects. The full scale drop test utilizing direct measurements, while frequently subject to instrumentational difficulties, gives a direct measure of the drag for the conditions of a particular flight. The curve finally utilized for the preparation of bombing tables is the result, generally, of all available data but is finally adjusted to give the best fit of impact and time of flight measurements of a large series of drops involving many release conditions. Hence, it is an average of some sort that represents, possibly, a wide variety of flight conditions.

The evidence indicates that the model data agree with the bombing table curve only if certain yaw conditions can be assumed. The question is then raised as to whether the actual bomb drops used in the trajectory calculations exhibited sufficient yaw, on the average, to explain the difference between the model data and the bombing table drag curve. If yaws of a proper level existed the data are compatible; if not, there would be an essential disagreement between the model and the full scale data that would seriously reduce the usefulness of model data in assisting the preparation of bombing tables.

The evidence of several accelerometer drop tests[6] appeared to show that the prevailing yaw levels in a drop could explain, at best, only the discrepancies in the subsonic portion of the drag curve (it should be noted that these drops were made without bomb bay doors and with the bomb semi-externally slung). However a series of Askania yaw and drag determinations from drop tests which were used to determine the bombing table curve[1] were available. The results of 18 drops from B-36 and B-45 aircraft at altitudes of 25,000, 35,000, 40,000 and 45,000 feet were

[1] This material was furnished by Mr. E. S. Martin of the Bombing Tables Branch of the Computing Laboratory.

investigated. The measured yaw was converted to plots of $\bar{\delta}^2$ as a function of time; the drag coefficients and a function of the total drag were also plotted. These records indicated a higher yaw level than was anticipated from the accelerometer data, particularly in the higher Mach number regions. Yaw data of this nature has an accuracy level of, say, two degrees. The sample curves (Figs. 19, 20) show levels of yaw from 2^{o2} to over 10^{o2} along large portions of the trajectory[2].

Figure 21 shows a comparison of the measured drag function ($K_D \rho V^2$) on several full scale bomb drops; the bombing table curve; and the model curve with a yaw correction for 4 degrees, average yaw. It appears that either the table curve or the yaw corrected model curve represents the general trend of the actual drags quite well.

CONCLUSIONS

Drag data obtained from free flight range model firings at reasonably high Reynolds numbers appear sufficient to serve as the basis for bombing tables, provided that scale corrections are applied to the model data, and provided that the yaw level in the full scale drops is quite small.

When full scale drop conditions include significant yaws, agreement with model data can be achieved by determining the yaw level and adjusting the model data accordingly.

ACKNOWLEDGEMENT

The author wishes to acknowledge the assistance of E. J. Roschke who materially helped this investigation.

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[2]Since the period of the bomb is on the order of a second the graphs are drawn to show gross overall variations in the yaw not detailed variations.

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TABLE I

MODEL PHYSICAL DATA

	Forward Center of Gravity	Mean Center of Gravity
Weight (lbs.)	31.32 (average)	19.57 (average)
Diameter (inches)	4.433 ± .002	4.433 ± .002
Length (inches)	33.84 ± .02	33.83 ± .02
c.g. (inches from base)	23.11	18.79
Axial Moment (lb. -in.^{2})	71.50	48.52
Transverse Moment (lb. - in^2)	2592.0	1779.1

TABLE II

RANGE DATA

Mach No.	K_D	C_D	% Error	σ^2
1.226	.2091	.5325	.22	2.3
1.207	.2061	.5248	.07	3.12
1.196	.2062	.5251	.40	7.25
1.189	.2030	.5169	.15	5.12
1.177	.2010	.5118	1.50	2.76
1.110	.1938	.4935	.50	5.8
1.103	.1872	.4767	.24	4.83
1.096	.1876	.4777	.10	2.2
1.093	.1853	.4719	.13	3.32
1.085	.1841	.4688	.02	1.44
1.077	.1765	.4495	2.3	1.74
1.067	.1750	.4456	2.6	1.77
1.058	.1735	.4418	.13	1.12
1.050	.1739	.4428	.65	.72
1.040	.1642	.4181	.36	.2
1.024	.1594	.4059	.11	.1
1.011	.1514	.3855	.59	.05
1.008	.1463	.3725	.44	3.6
1.005	.1365	.3476	.23	5.42
1.001	.1324	.3372	.38	4.14
.998	.1375	.3501	.49	1.21
.996	.1269	.3231	1.77	2.77
.992	.1317	.3354	.15	.89
.986	.1266	.3224	.78	.59
.982	.1272	.3239	.79	6.96
.976	.1155	.2941	.71	4.17
.972	.1064	.2709	.45	2.6
.971	.1014	.2582	.54	.7
.958	.0931	.2371	.93	1.61
.954	.0918	.2338	.15	.98
.949	.0915	.2330	.97	.56
.936	.0848	.2159	.28	2.82
.932	.0931	.2371	1.0	11.19
.928	.0838	.2134	.16	6.80
.925	.0825	.2101	1.3	3.97
.911	.0724	.1844	.3	1.65
.899	.0665	.1683	.95	3.6
.887	.0604	.1538	1.6	2.63
.884	.0599	.1525	.22	1.67
.882	.0599	.1525	.51	1.21

TABLE II (Cont'd)

Mach No.	K_D	C_D	% Error	δ^2
.786	.0565	.1439	.85	6.24
.786	.0516	.1314	1.35	2.66
.784	.0522	.1329	.27	1.80
.782	.0518	.1319	1.3	1.25
.723	.0533	.1357	.28	1.4
.718	.0578	.1472	1.3	2.16
.716	.0497	.1266	.26	1.38
.713	.0490	.1248	.24	.9
.700	.0257	.1342	2.9	5.09
.698	.0524	.1334	.47	2.9
.696	.0512	.1304	.73	1.59

TABLE III

DRAG COEFFICIENT AT ZERO YAW

M	K_{D_0}	C_{D_0}
.70	.0500	.1273
.80	.0505	.1286
.84	.0507	.1291
.85	.0510	.1300
.86	.0520	.1324
.87	.0540	.1375
.88	.0570	.1452
.80	.0655	.1668
.92	.0740	.1884
.94	.0830	.2114
.95	.0870	.2215
.96	.0930	.2368
.97	.1000	.2547
.980	.1140	.2903
.990	.1280	.3260
1.000	.1400	.3565
1.01	.1500	.3820
1.02	.1560	.3973
1.03	.1615	.4113
1.04	.1663	.4235
1.05	.1705	.4342
1.06	.1745	.4444
1.07	.1775	.4520
1.08	.1810	.4609
1.09	.1835	.4673
1.10	.1860	.4736
1.11	.1875	.4775
1.12	.1895	.4826
1.13	.1913	.1871
1.14	.1930	.4915
1.15	.1945	.4953
1.16	.1960	.4991
1.17	.1975	.5029
1.20 → 1.22	.2033	.5177

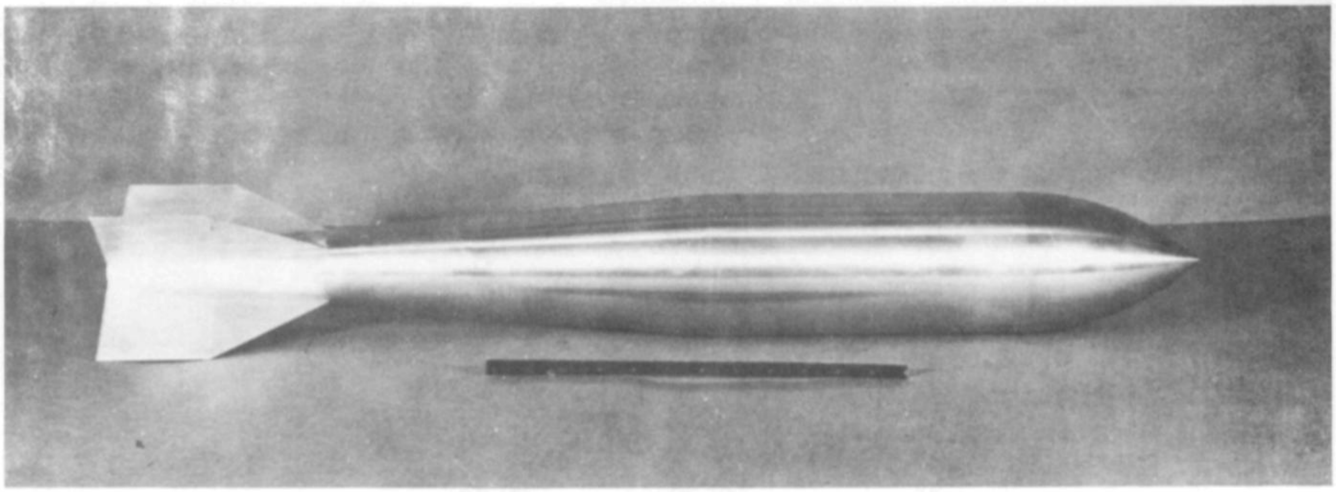

FIG. 1. MODEL BOMB

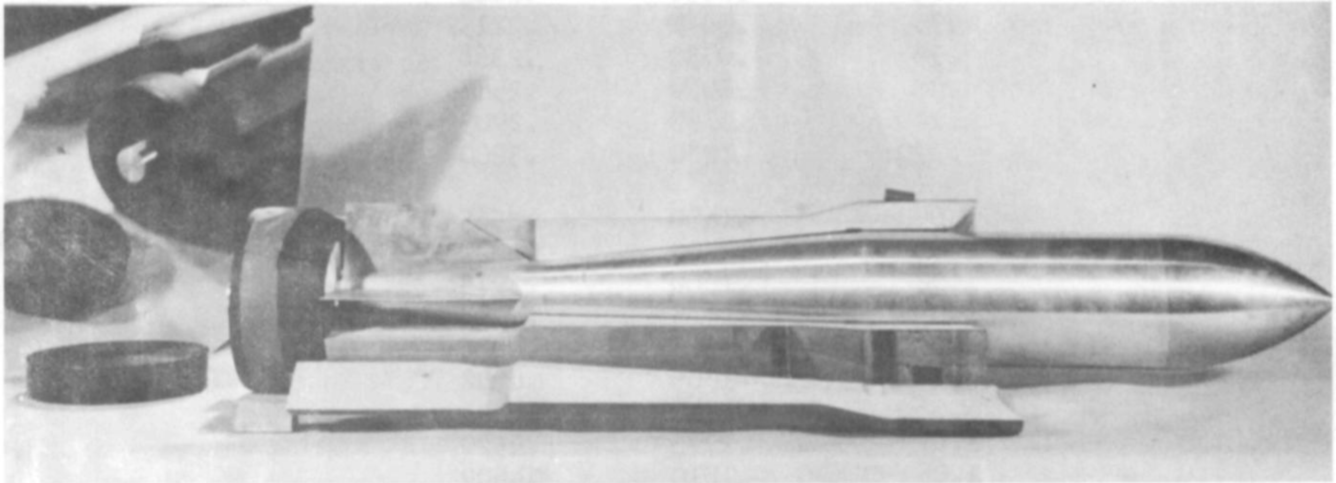

FIG. 2. MODEL IN OPEN SABOT

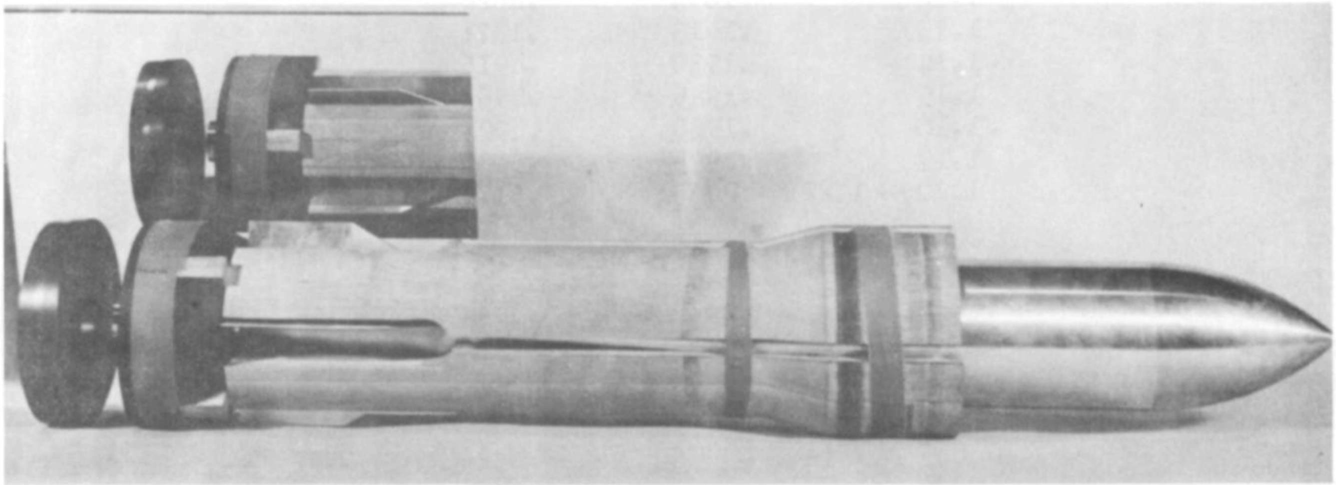

FIG. 3. SABOT ASSEMBLED

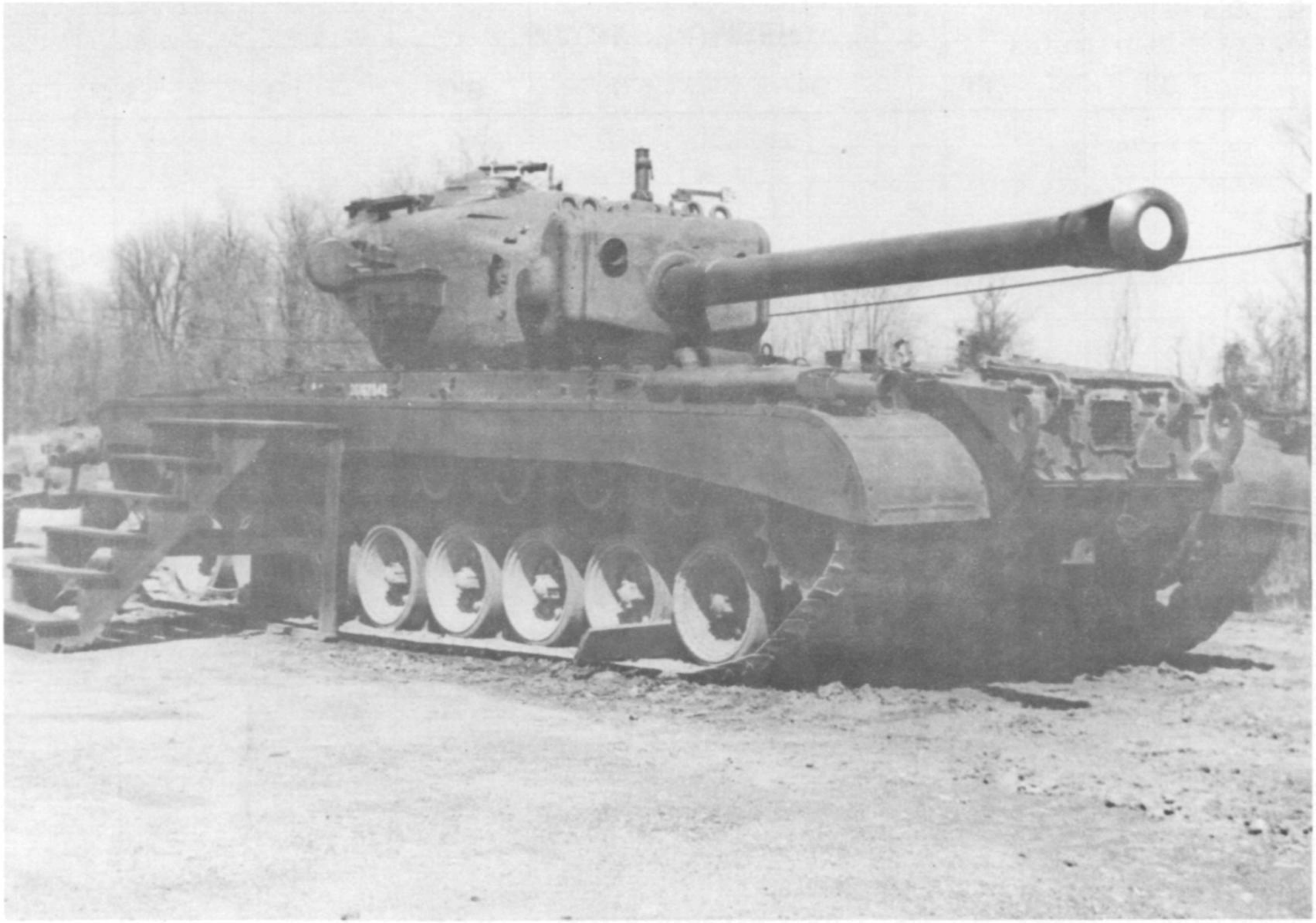

FIG. 4. 155MM SMOOTH BORE IN TANK MOUNT

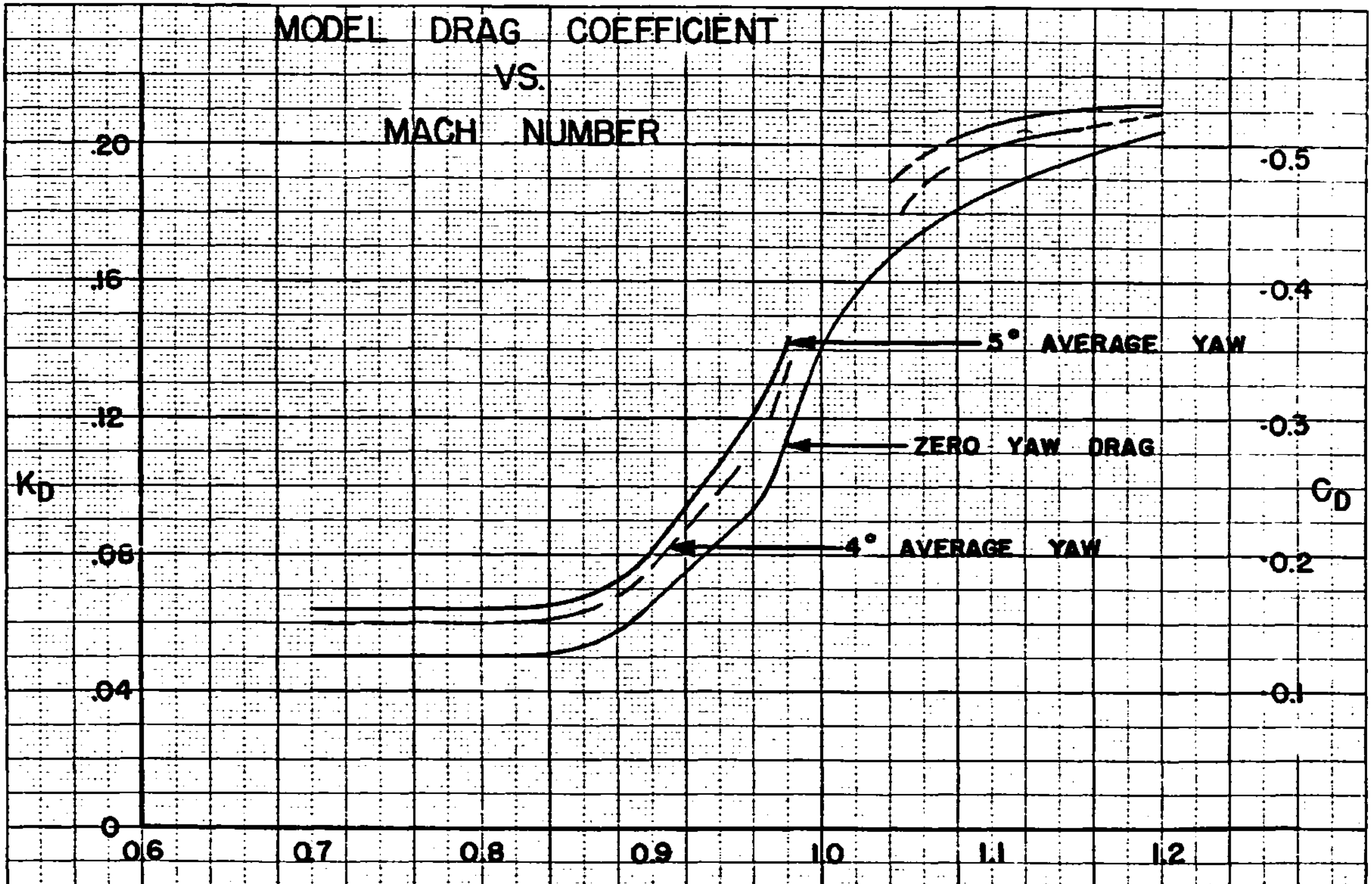
MODEL DRAG COEFFICIENT
VS.
MACH NUMBER
K_D
.20
.16
.12
.08
.04
0
0.6
0.7
0.8
0.9
1.0
1.1
1.2
MACH NUMBER
C_D
-0.5
-0.4
-0.3
-0.2
-0.1
5° AVERAGE YAW
ZERO YAW DRAG
4° AVERAGE YAW

FIG. 5

YAW DRAG COEFFICIENT

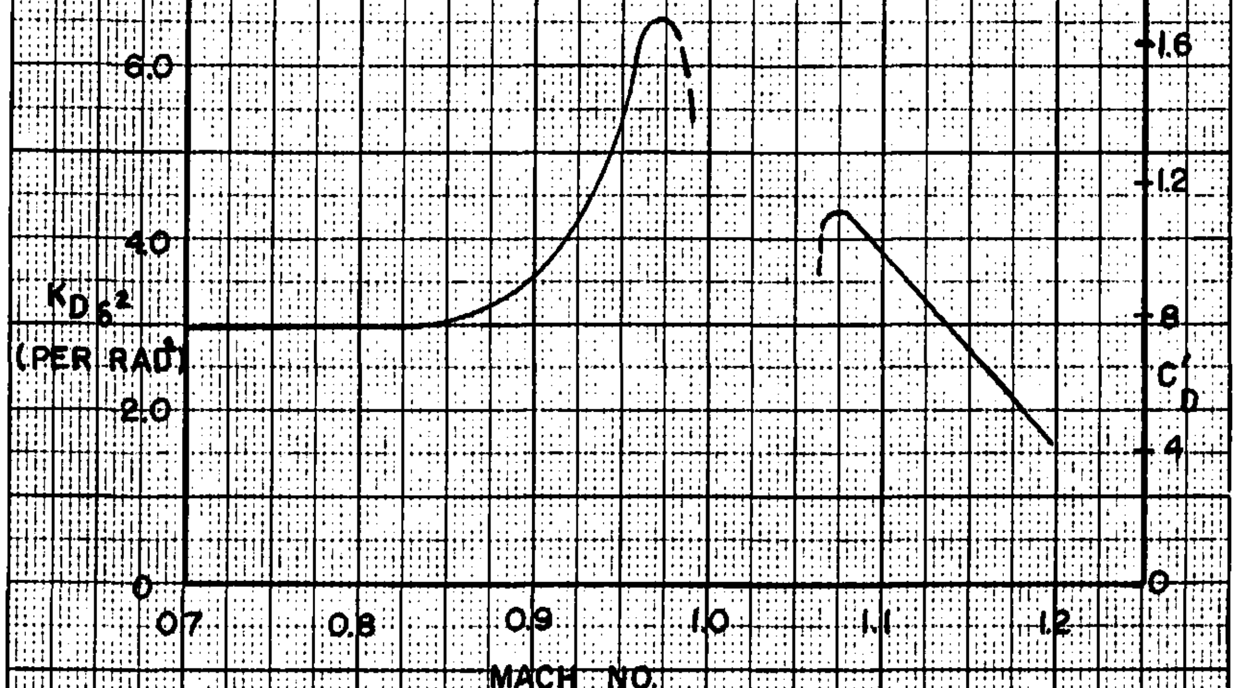

FIG. 6

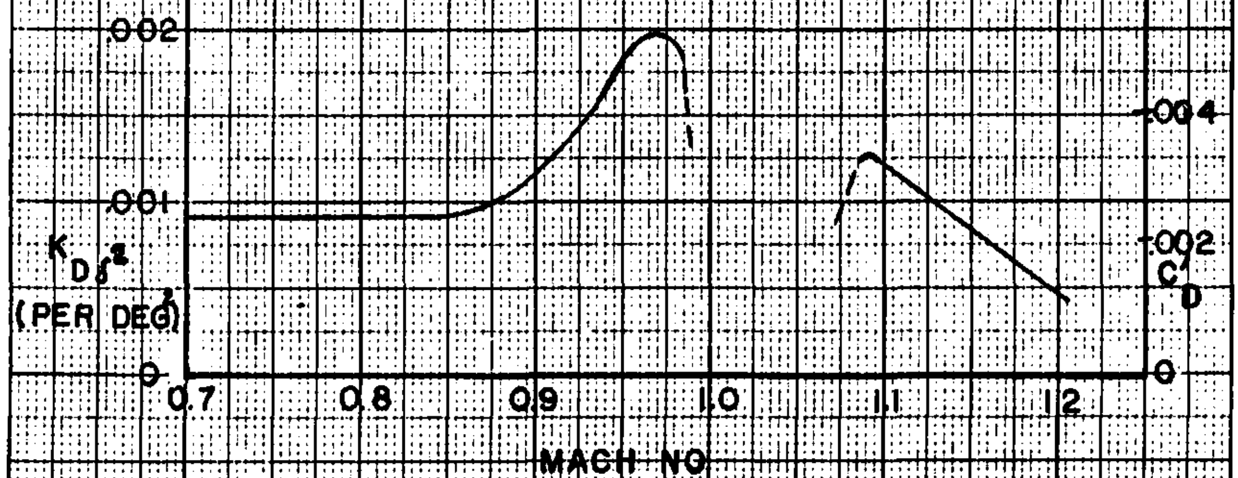

FIG. 7

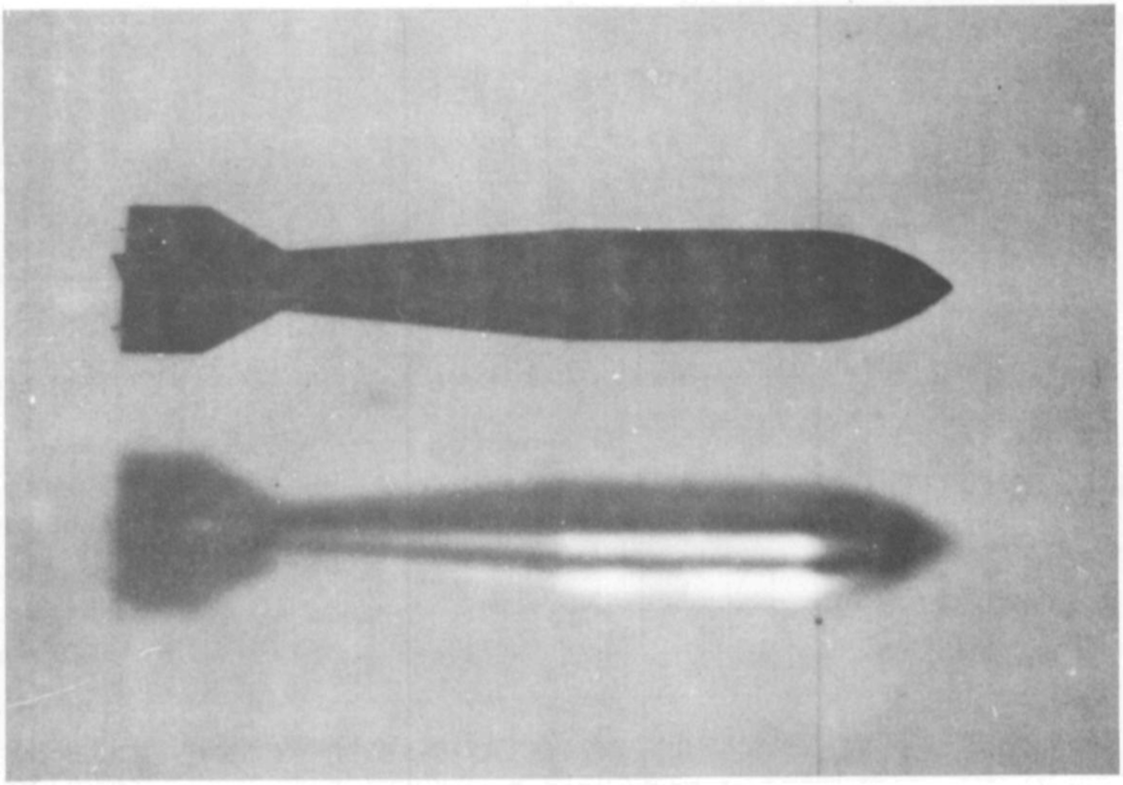

FIG. 8 M = 0.70

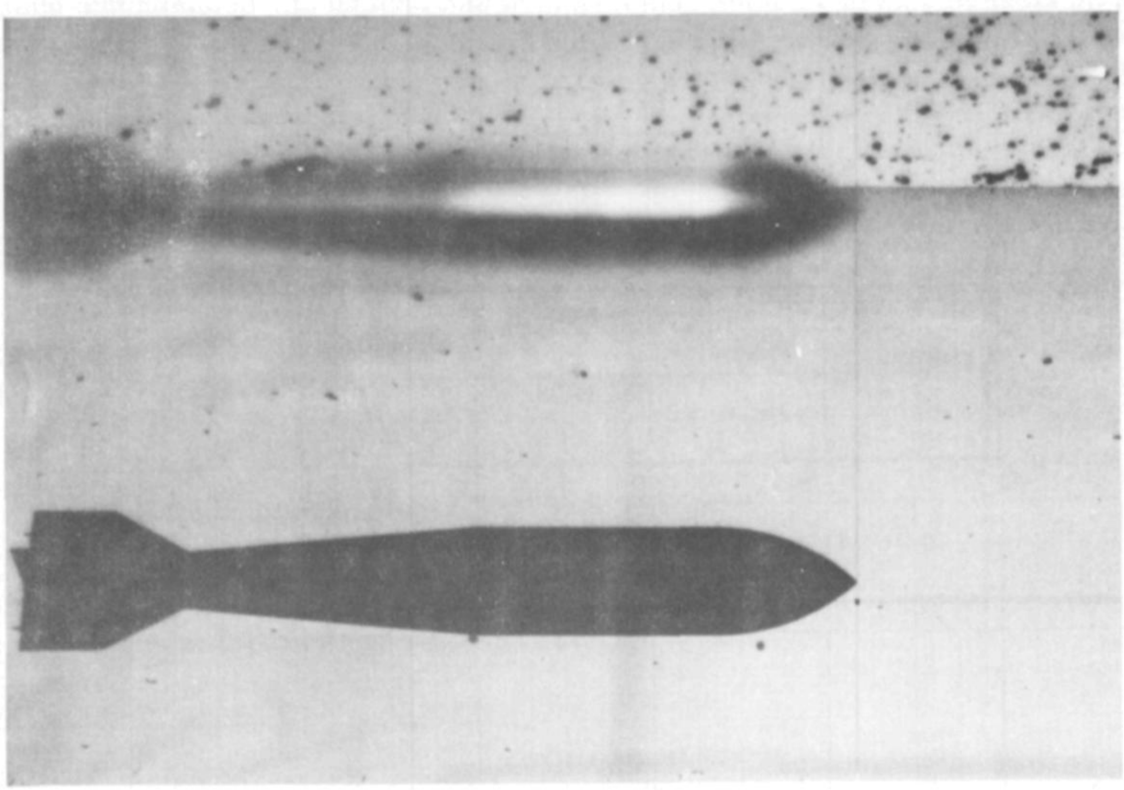

FIG. 9 M = 0.78

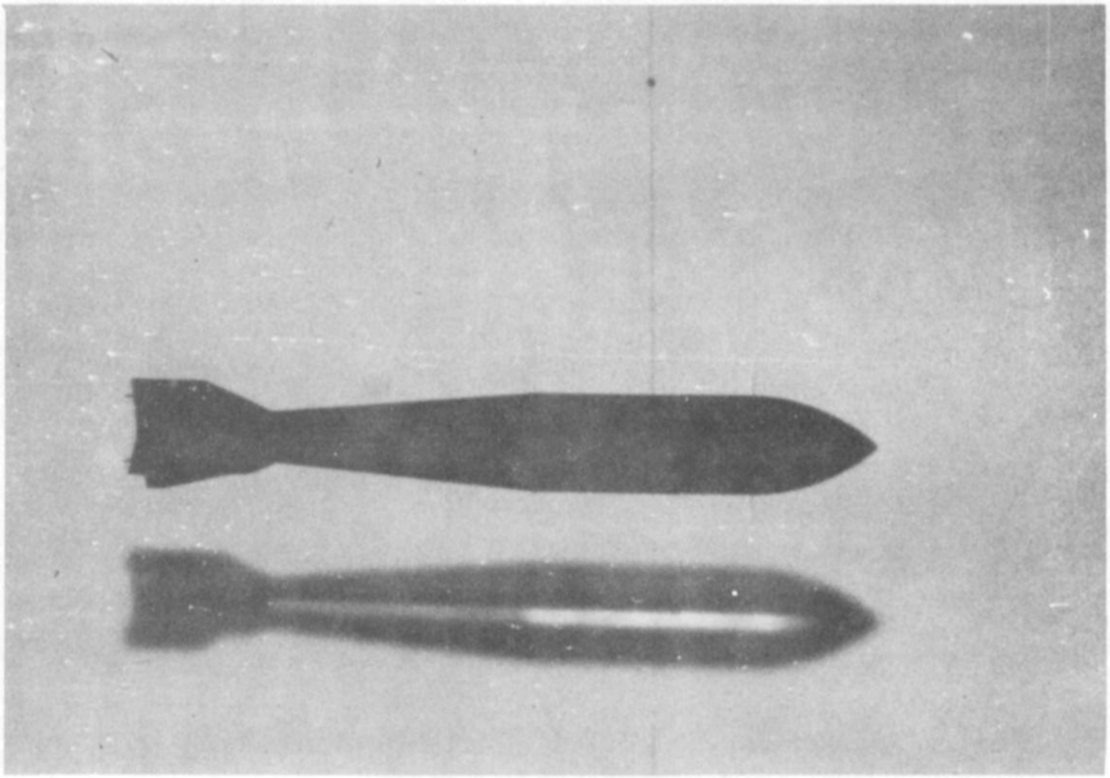

FIG. 10 M = 0.855

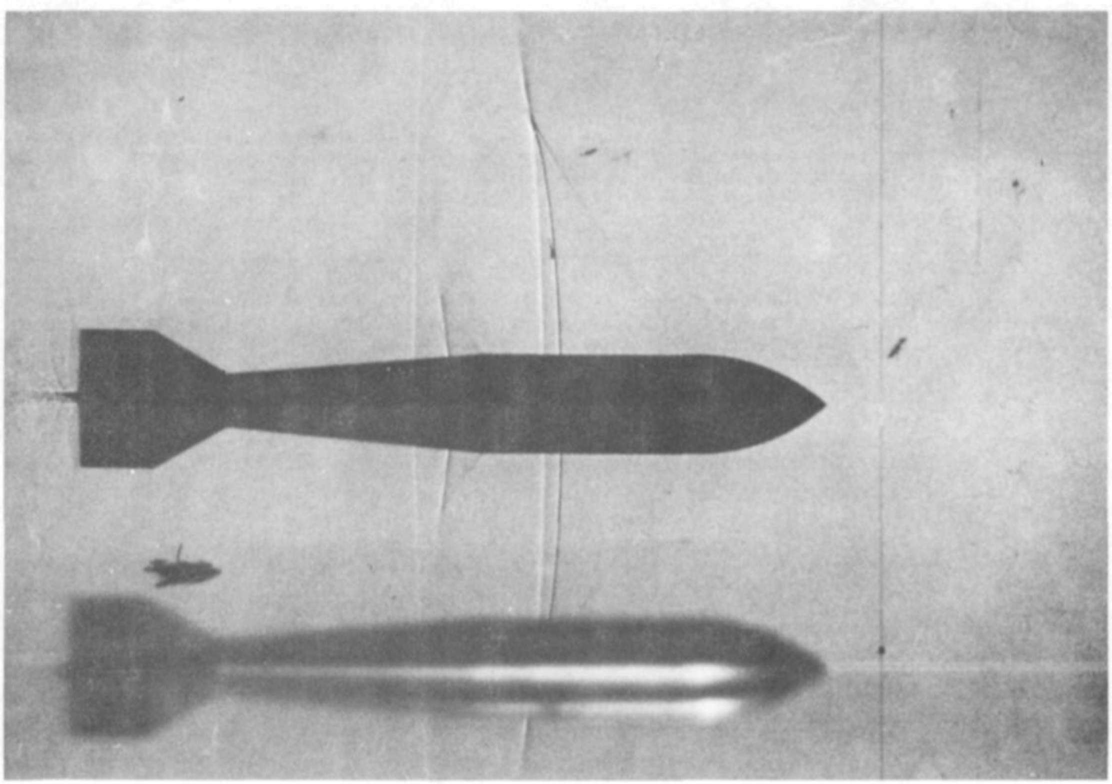

FIG. 11 M = 0.96

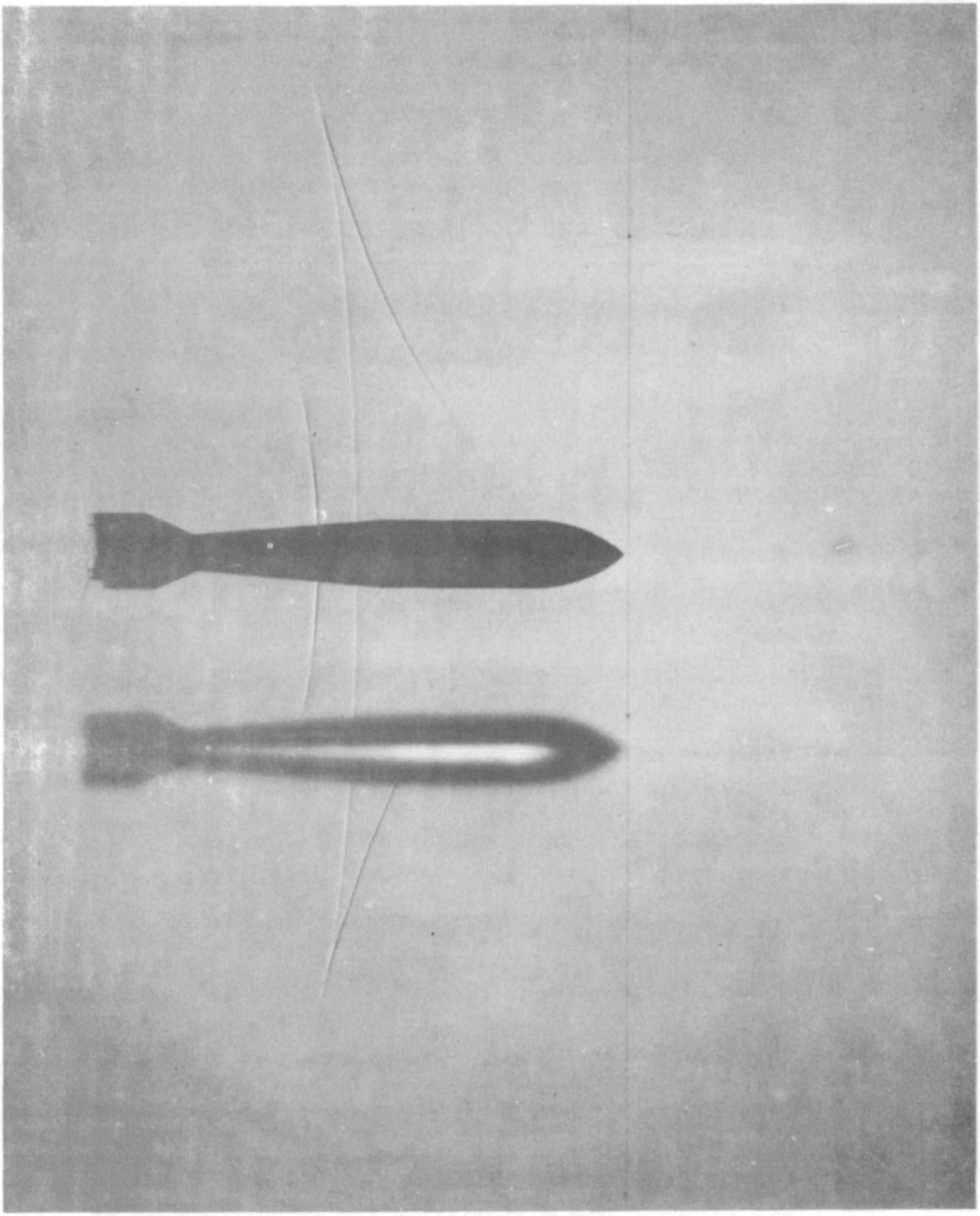

FIG. 12 M = 0.98

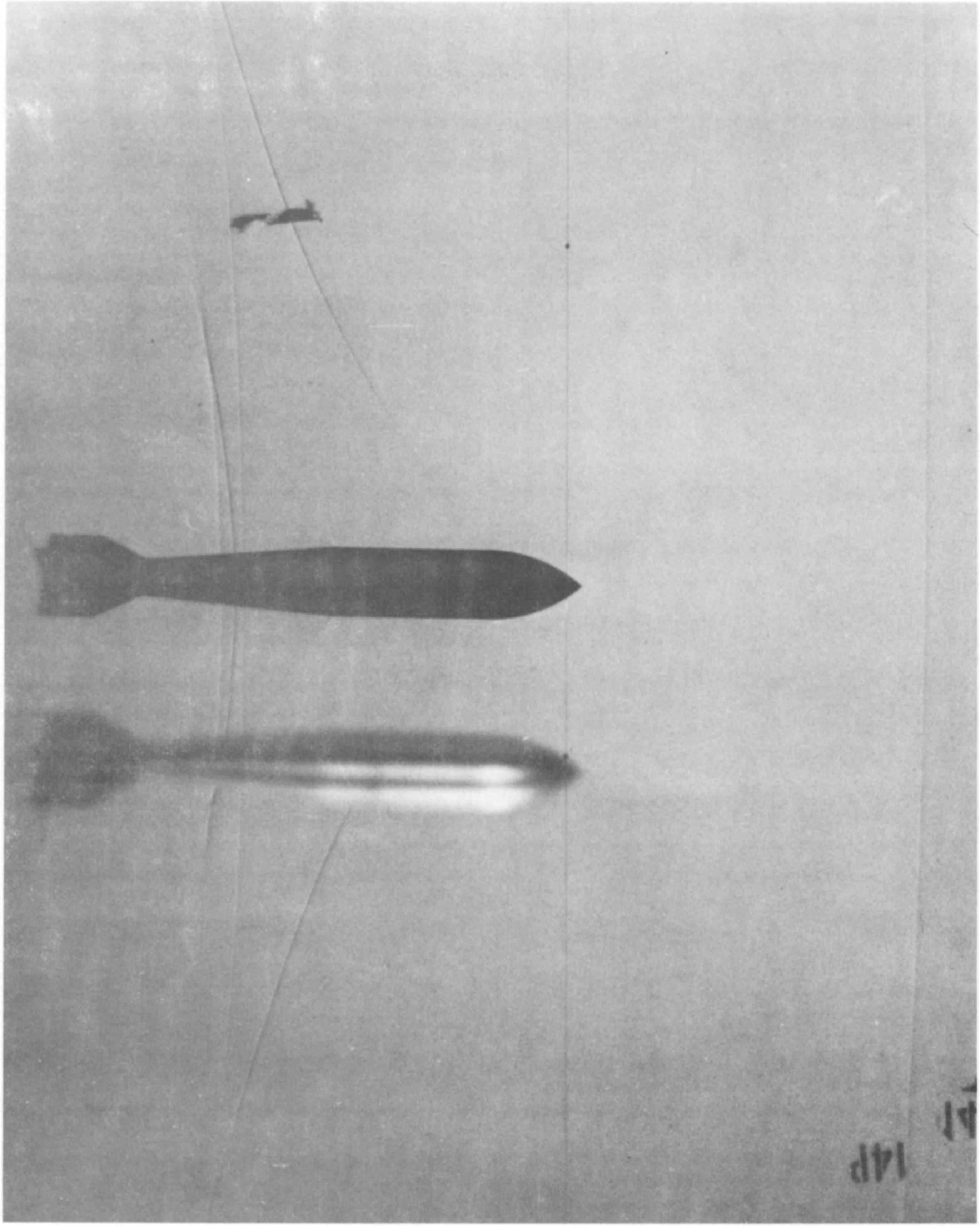

FIG. 13 $M = 1.00^{+}$

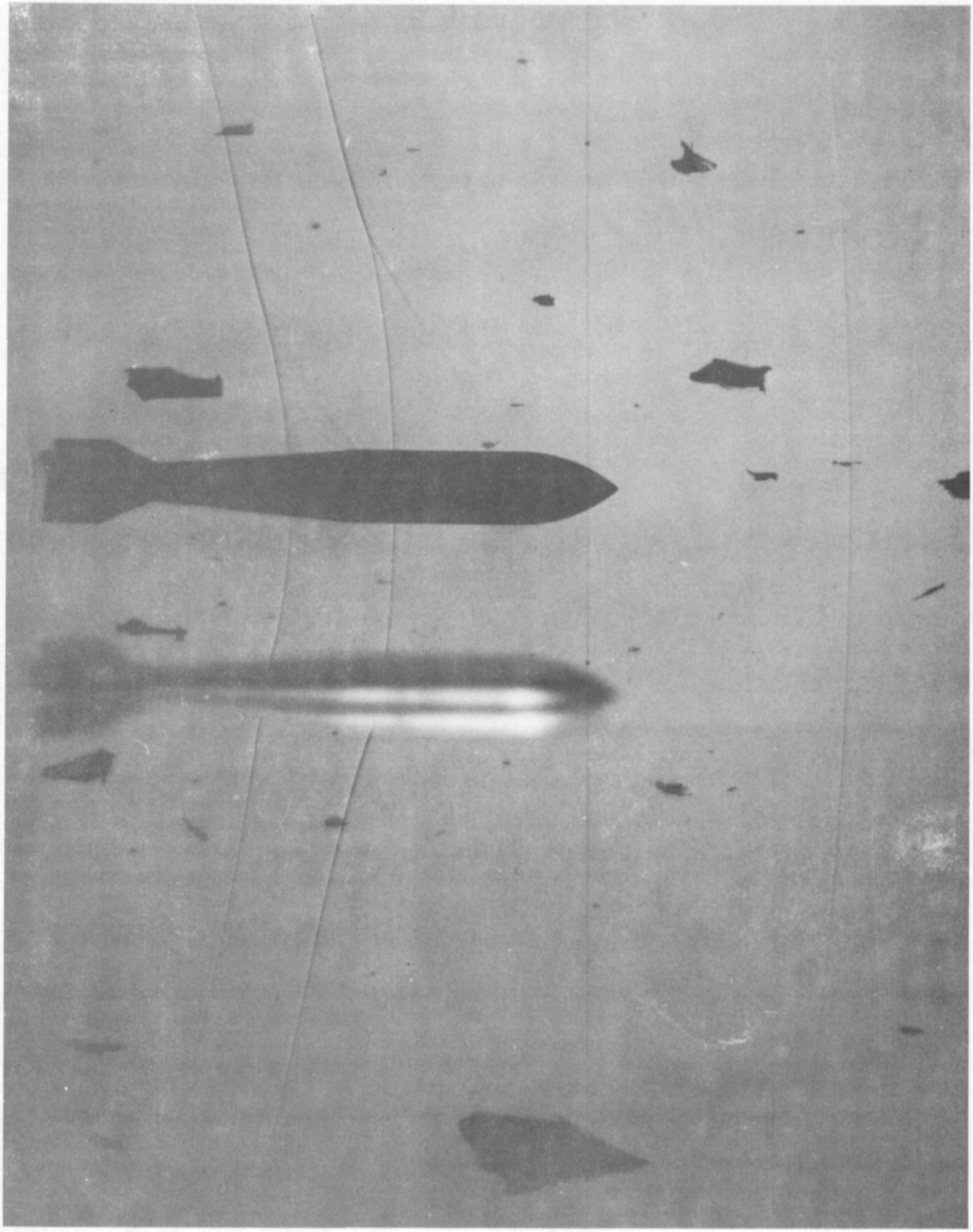

FIG. 14 $M = 1.005$

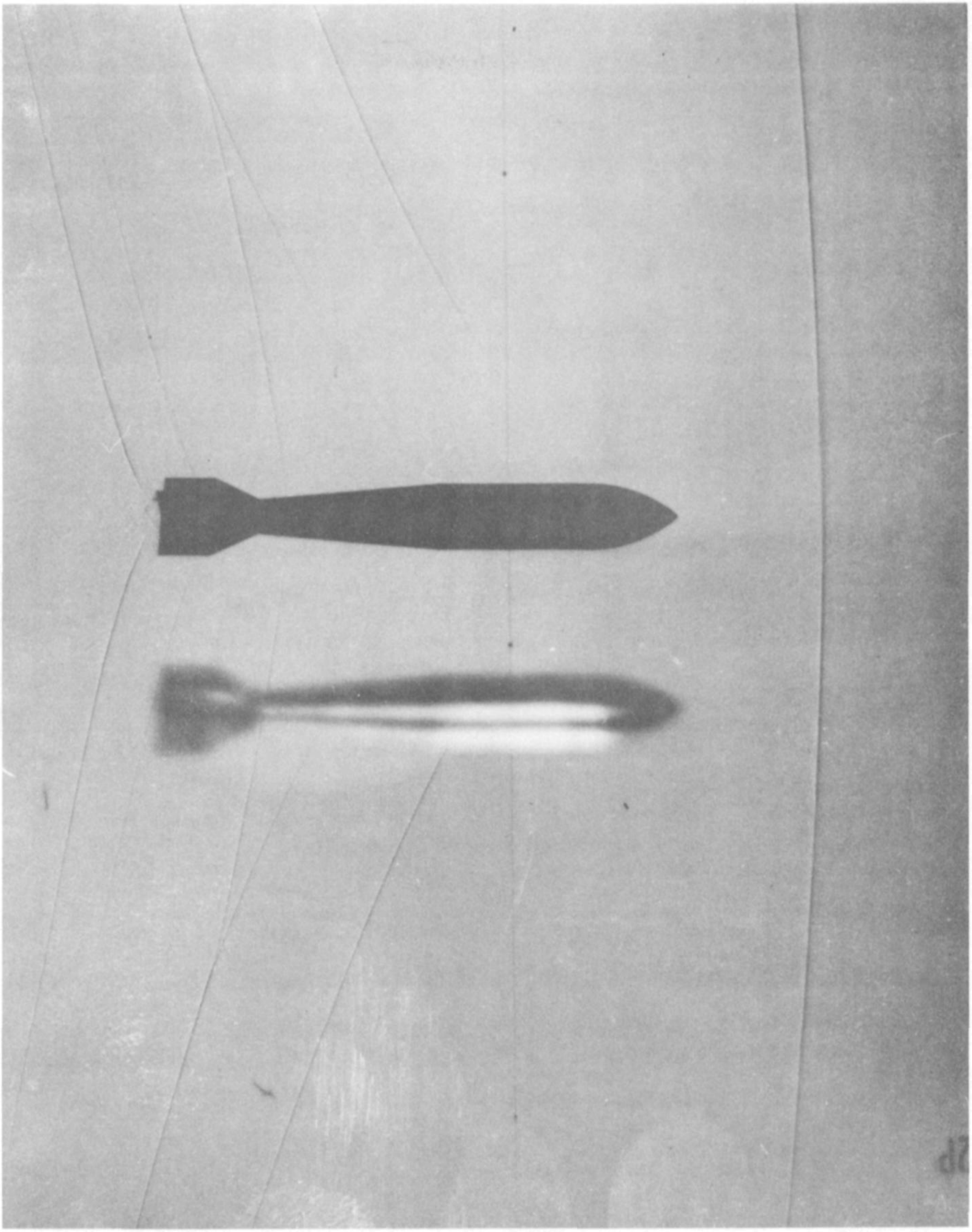

FIG. 15 M = 1.10

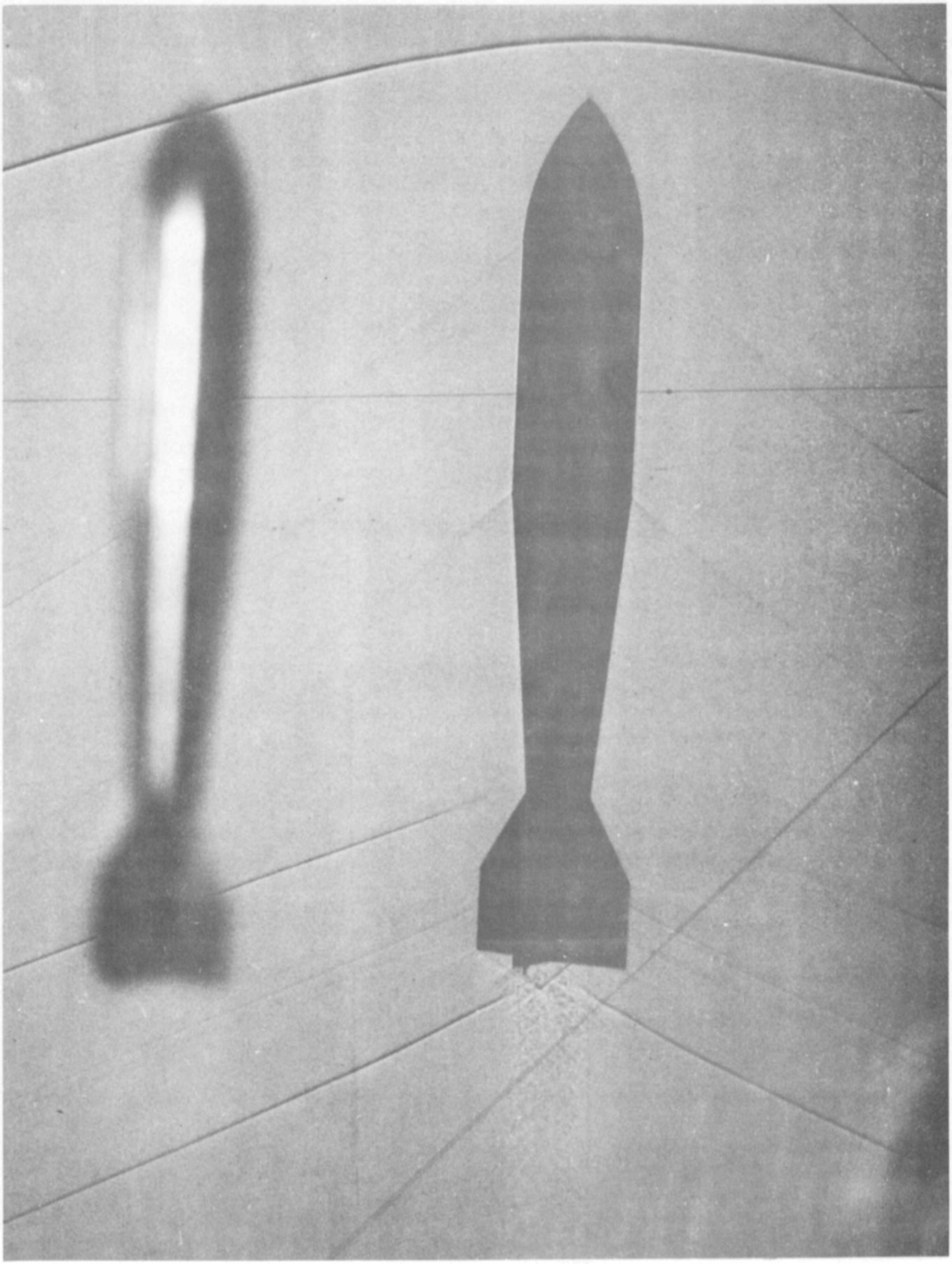

FIG. 16 M = 1.25

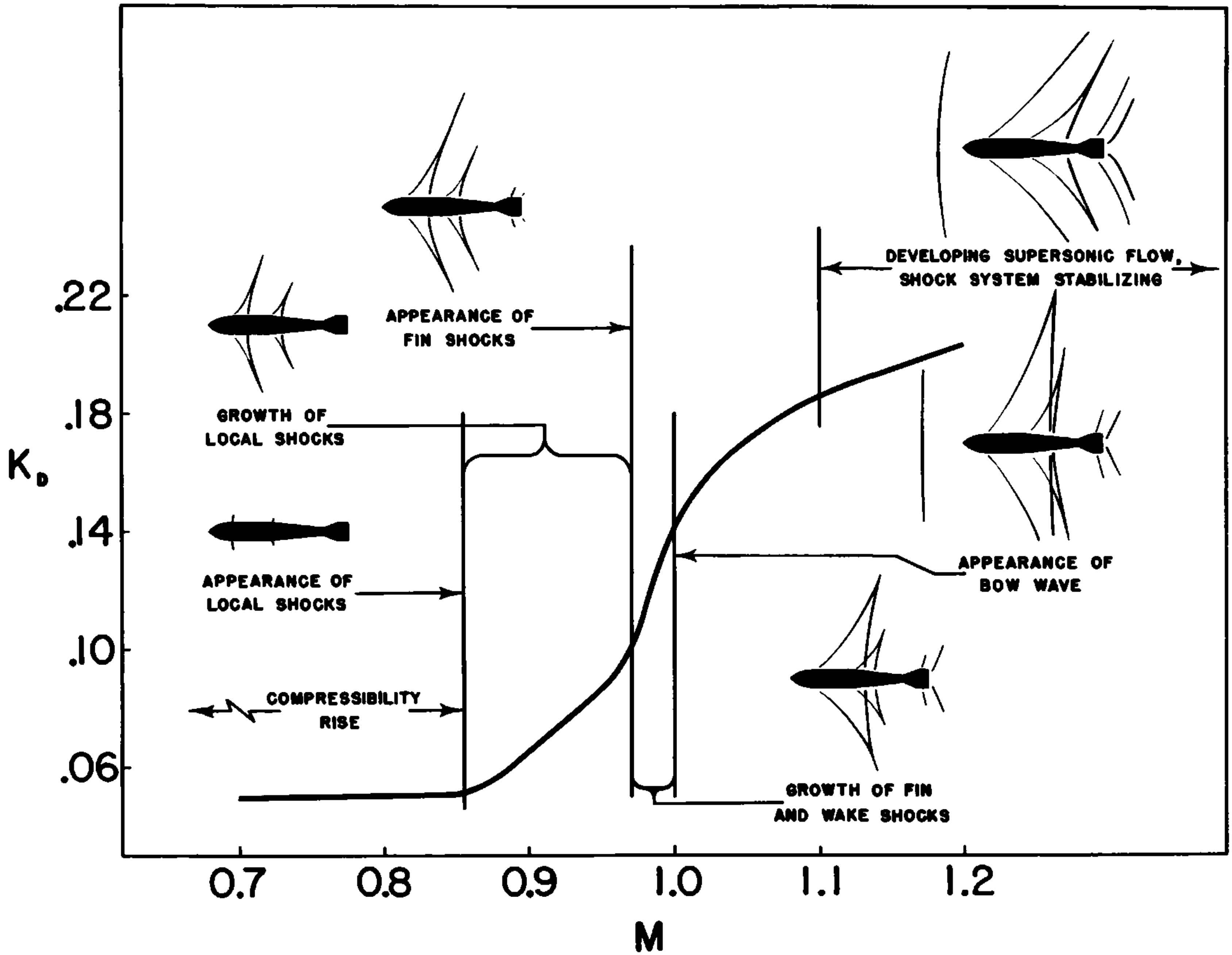

FIG. 16 A CORRELATION OF FLOW FIELDS AND DRAG CHARACTERISTICS

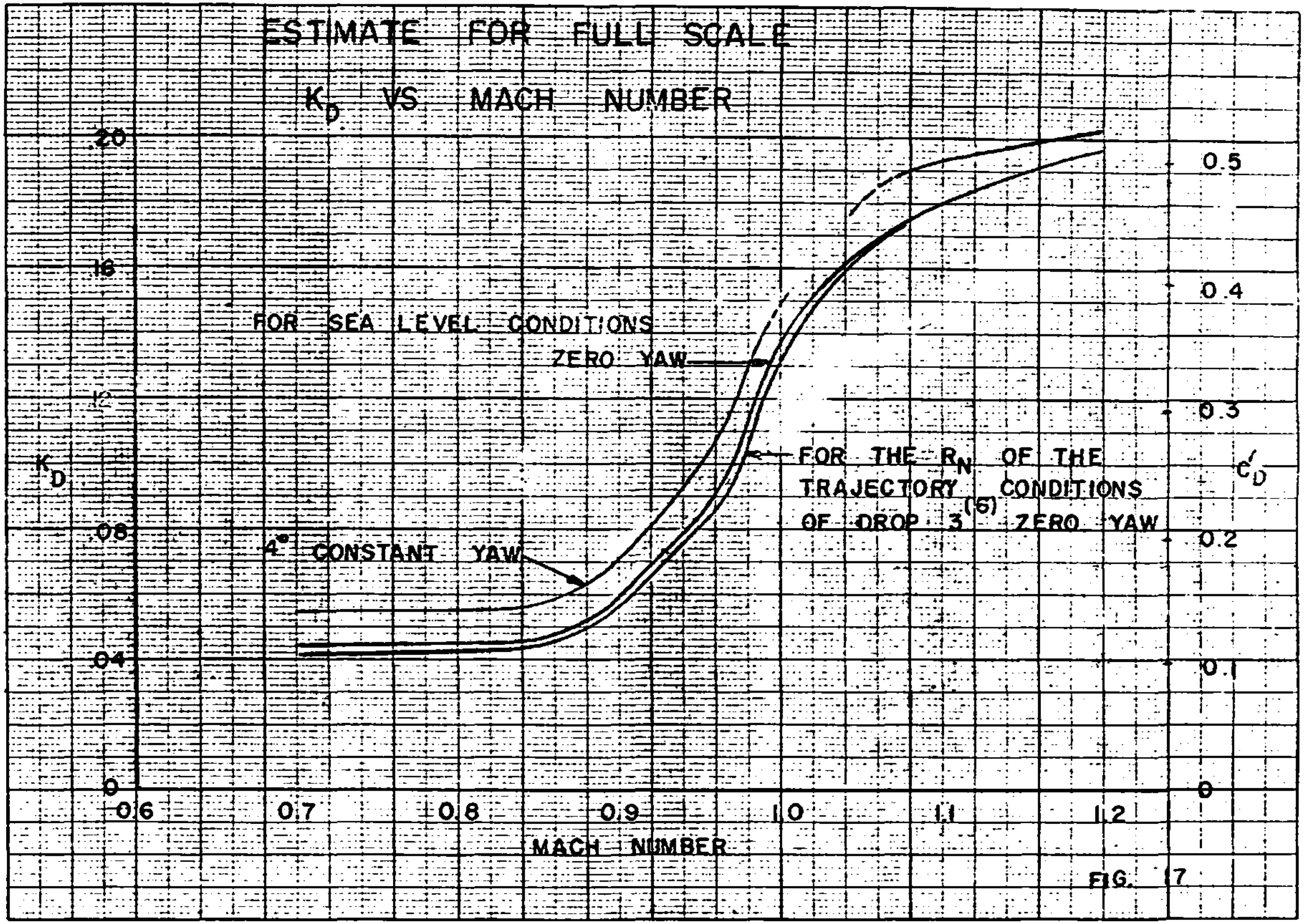
ESTIMATE FOR FULL SCALE
K_D VS MACH NUMBER
.20
.16
.12
.08
.04
0
K_D
0.5
0.4
0.3
0.2
0.1
0
C_D'
FOR SEA LEVEL CONDITIONS
ZERO YAW
FOR THE R_N OF THE
TRAJECTORY CONDITIONS
OF DROP 3 (6) ZERO YAW
4° CONSTANT YAW
0.6
0.7
0.8
0.9
1.0
1.1
1.2
MACH NUMBER

FIG. 17

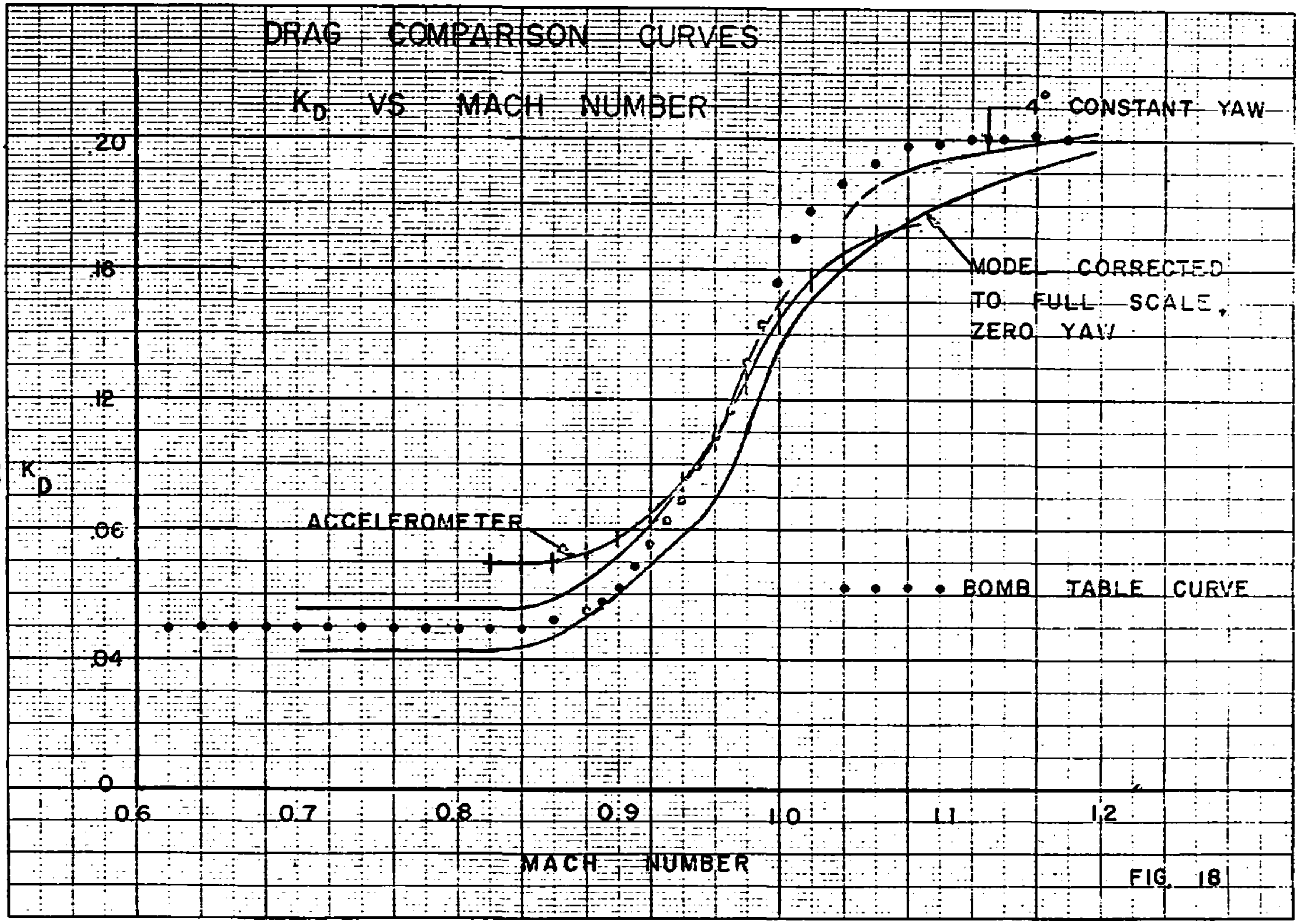
DRAG COMPARISON CURVES
K_D VS MACH NUMBER
4° CONSTANT YAW
MODEL CORRECTED TO FULL SCALE, ZERO YAW
ACCELEROMETER
BOMB TABLE CURVE
K_D
.20
.16
.12
.06
.04
0
0.6
0.7
0.8
0.9
1.0
1.1
1.2
MACH NUMBER

FIG. 18

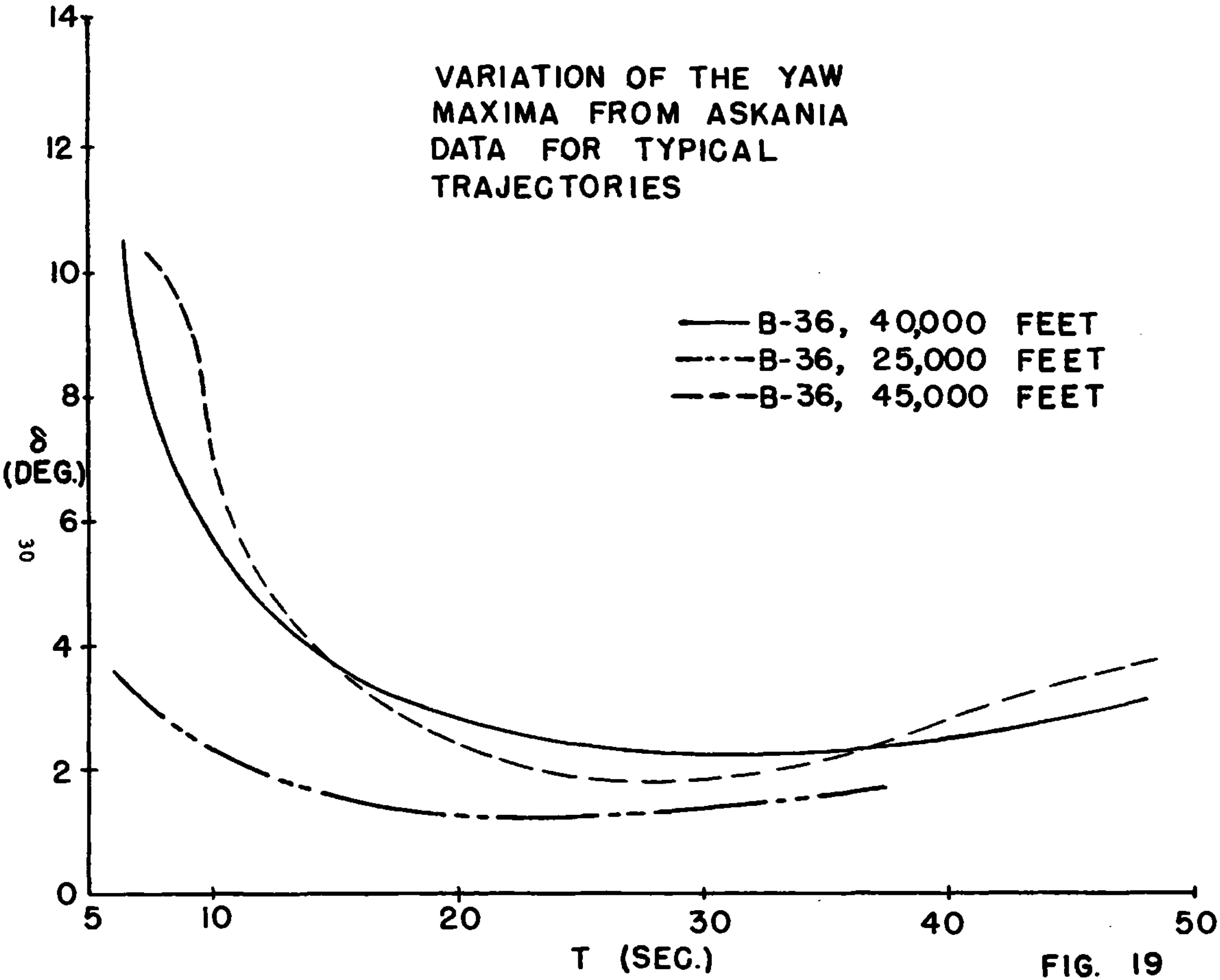
VARIATION OF THE YAW MAXIMA FROM ASKANIA DATA FOR TYPICAL TRAJECTORIES
B-36, 40,000 FEET
B-36, 25,000 FEET
B-36, 45,000 FEET
δ (DEG.)
T (SEC.)
0
2
4
6
8
10
12
14
5
10
20
30
40
50

FIG. 19

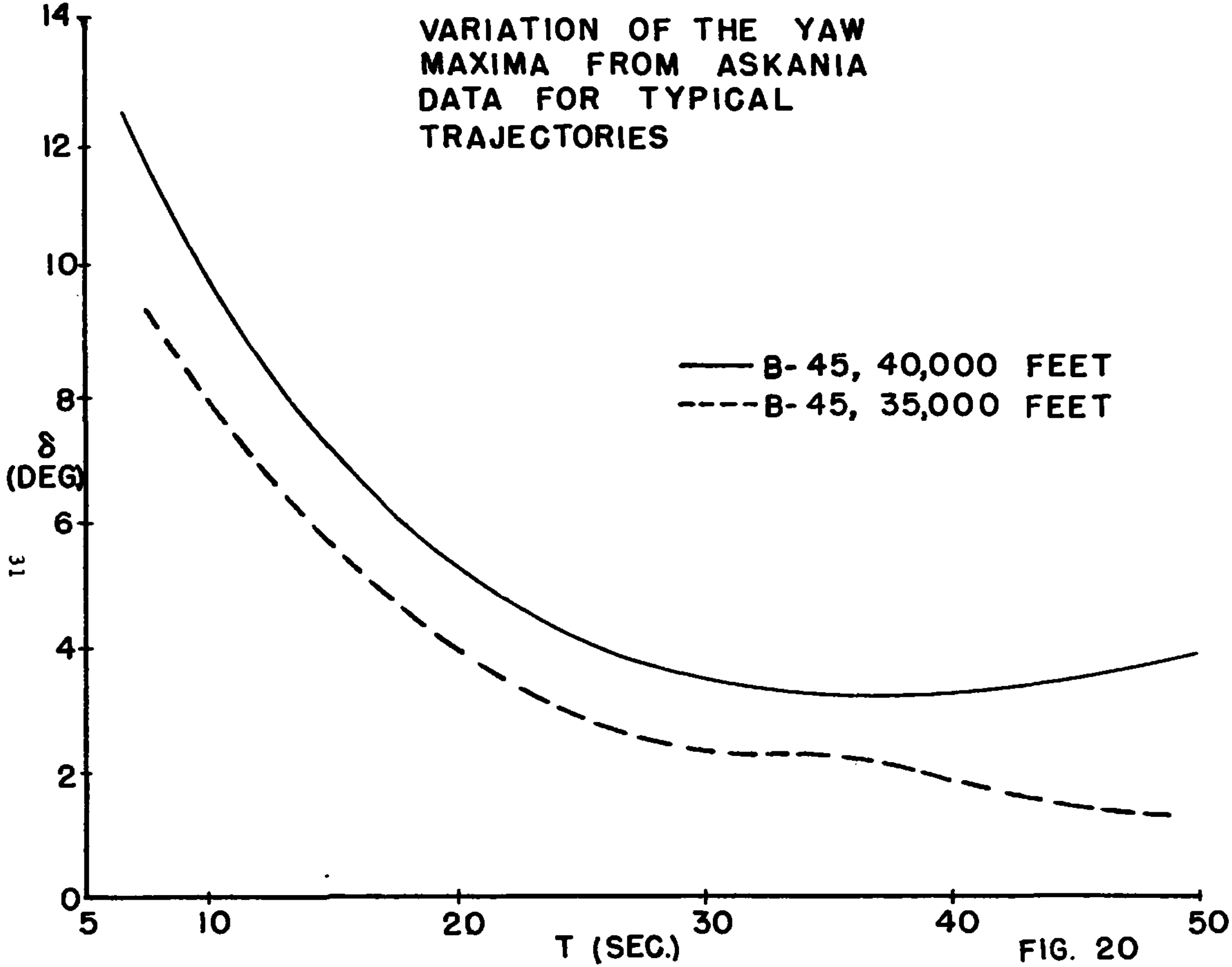
VARIATION OF THE YAW
MAXIMA FROM ASKANIA
DATA FOR TYPICAL
TRAJECTORIES
B-45, 40,000 FEET
B-45, 35,000 FEET
δ (DEG)
T (SEC.)
0
2
4
6
8
10
12
14
5
10
20
30
40
50

FIG. 20

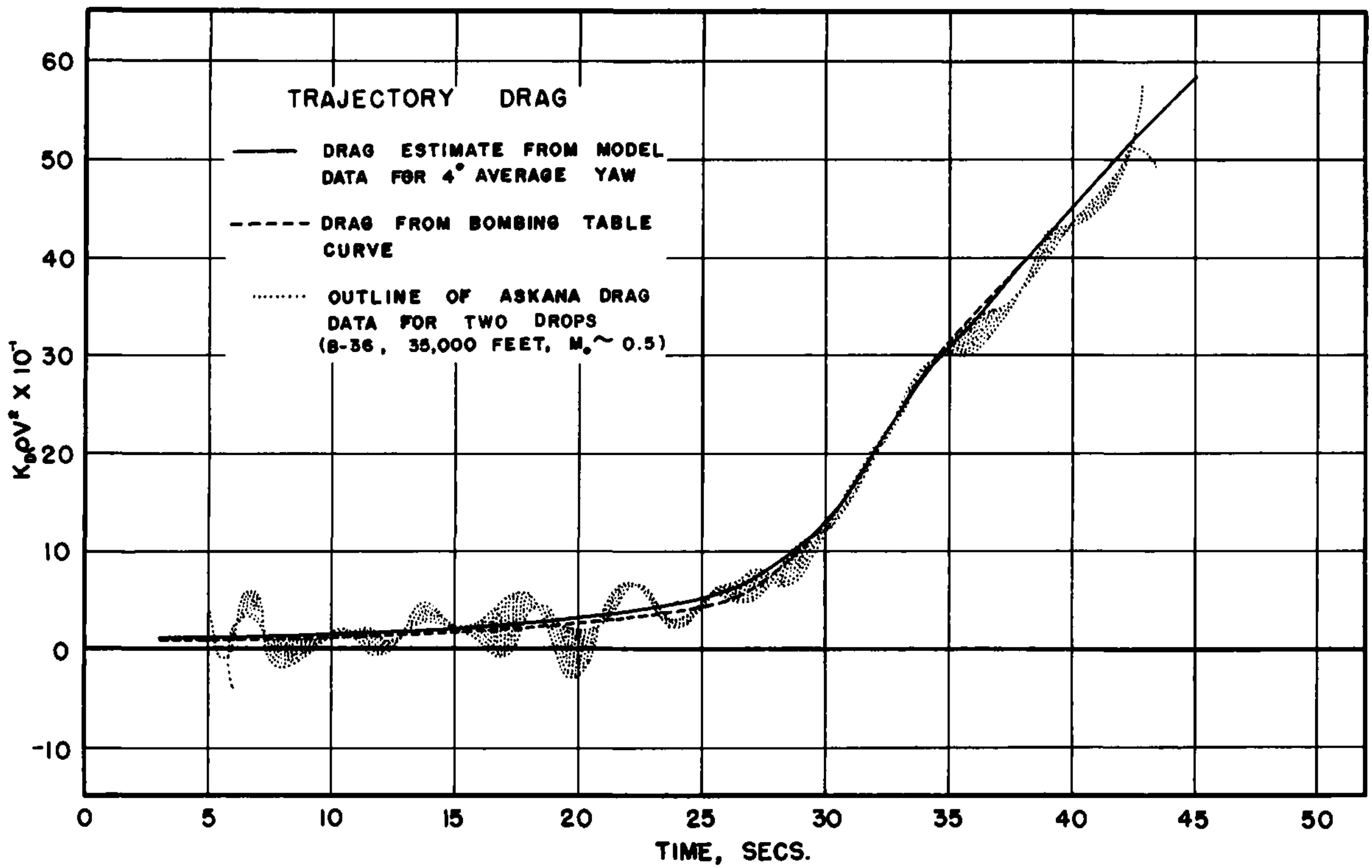
TRAJECTORY DRAG
DRAG ESTIMATE FROM MODEL DATA FOR 4° AVERAGE YAW
DRAG FROM BOMBING TABLE CURVE
OUTLINE OF ASKANA DRAG DATA FOR TWO DROPS
(B-36, 35,000 FEET, $M_o \sim 0.5$)
$K_D \rho V^2 \times 10^{-1}$
TIME, SECS.
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
30
35
40
45
50

FIG. 21

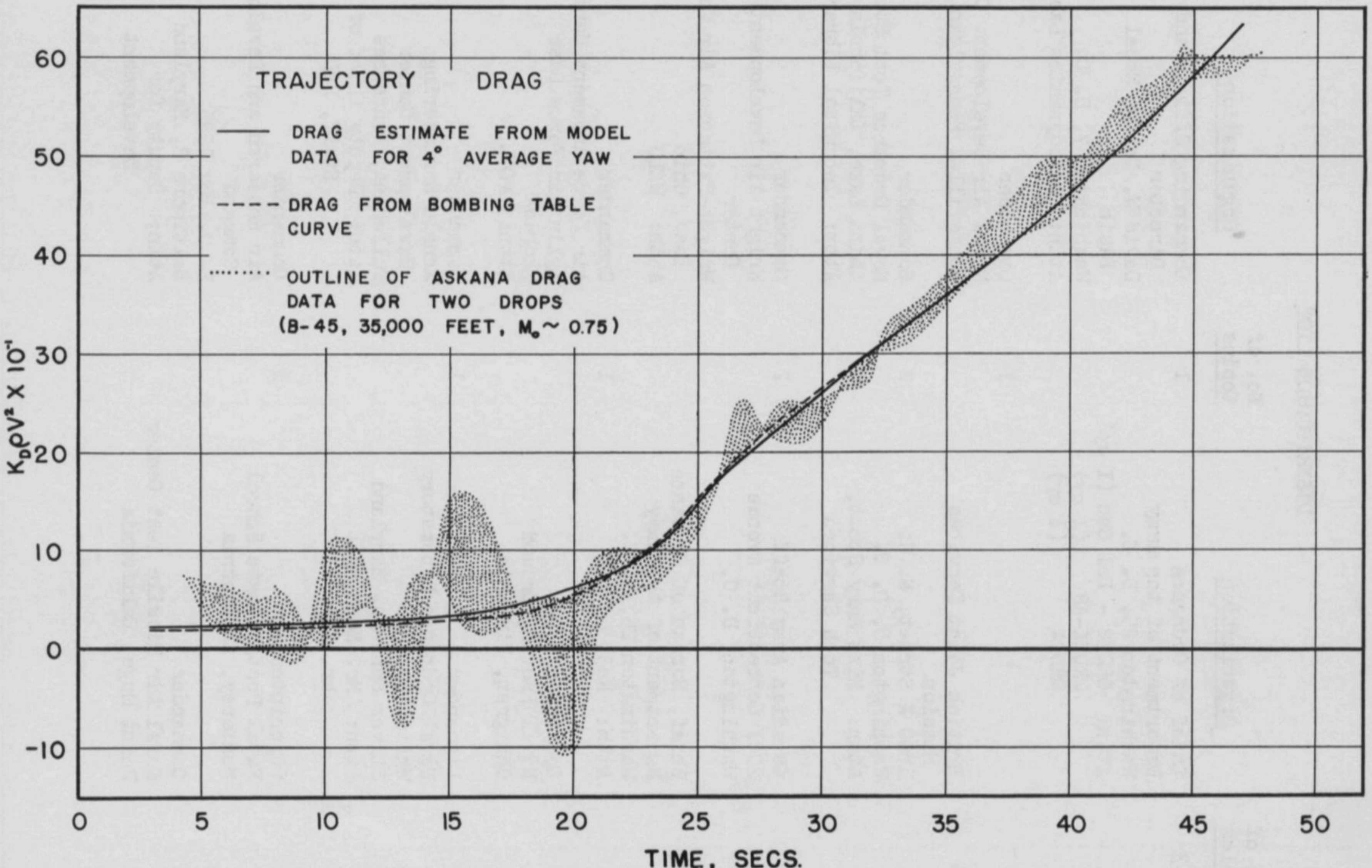
TRAJECTORY DRAG
DRAG ESTIMATE FROM MODEL DATA FOR 4° AVERAGE YAW
DRAG FROM BOMBING TABLE CURVE
OUTLINE OF ASKANA DRAG DATA FOR TWO DROPS (B-45, 35,000 FEET, $M_o \sim 0.75$)
$K_D \rho V^2 \times 10^{-1}$
TIME, SECS.
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
30
35
40
45
50

FIG. 22

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